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Suspended Gate Field Effect Transistor with an Integrated Micro-Fluidic Channel Performed by Surface Micromachining for Liquids Sensing

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Abstract

This paper presents original designs of micro-fluidic sensors. Targeted applications are pH-meters devices or chemical sensors. The sensing part of the device consists of a Suspended Gate Field Effect Transistor (SGFET). Chemicals to test are brought inside the device by a micro-fluidic channel. The floor of the channel consists on the drain, source and also active area of the transistor, whereas the top of the buried channel corresponding of the gate of the transistor. By this way products that flow in the micro-fluidic channel directly module the concentration charge inside the transistor's gap and thus induce changes in transfer characteristics. This paper describes the fabrication process and presents first electrical tests performed with liquid flow injection in the device showing the interest of the system.

Keywords: pH sensor, surface micro-machining, Field effect transistor, Microfluidic

1. Introduction

Chemical sensors are becoming an important tool used by biologists for diagnostic, in chemistry for pH measurement or also in environmental monitoring for gas detection. Among main kind of sensors, there are SGFET devices [1] which have already shown good properties in charges detection [2]. They have been used in pH measurement, biological species and gas detection [2,3]. In most cases and especially for

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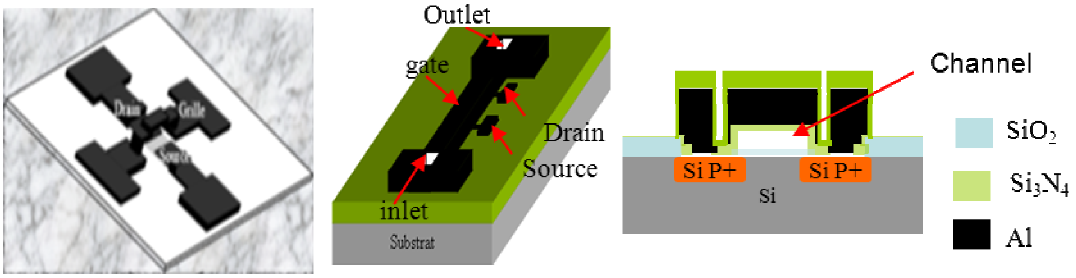
pH or biological species, electrical tests are performed in liquids. In order to perform pH measurement it is necessary to dive SGFET's (suspended bridge) into the solution [3]. As active area of sensor is located under the suspended gate (fig. 1a and 1b), it cannot be reached easily. Moreover accuracy and reliability depend on several parameters such as rinsing steps quality. Another technique consists in encapsulating SGFET with a PDMS (Polydimethyl siloxane) micro-fluidic device to drive chemicals flow nearby the sensor [4-5]. Even with this method, it is hard to insure the renewing used of the solution below the suspended gate. Indeed PDMS channels have several microns height whereas SGFET gaps are below 1µm, so active area of SGFET are still in the boundary layer of the chemical flow. One solution is to integrate à microfluidic channels within field effect transistor (fig. 1c, 1d).



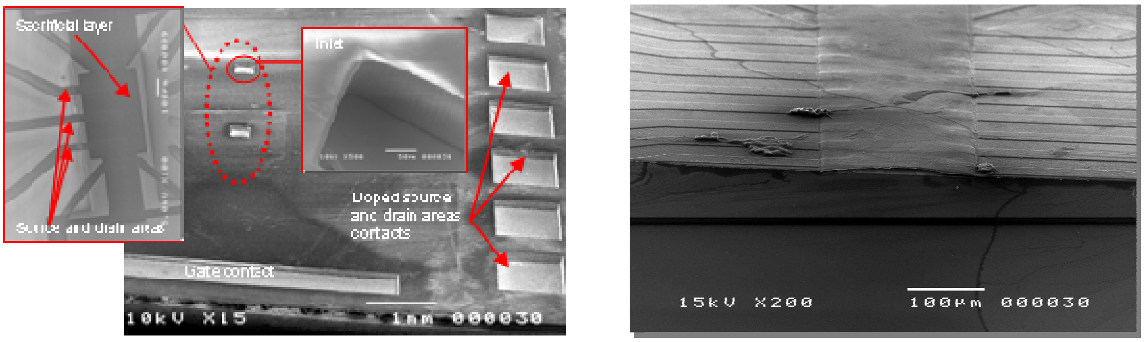
(a) (b) (c)

Fig. 1. (a) 3D scheme of usual SGFET, (b) 3D scheme of SGFET with micro-fluidic channel, (c) Schematic cross section of usual SGFET with micro-fluidic channel

So the aim of this work is to process SGFET with integrated micro-channel and to drive a liquid flow through this channel in order to test it electrically.

2. Sensor fabrication process

Sensors have been processed on an N type silicon wafer by surface micromachining associated to classical high temperature MOS process. The highly doped P+ regions (sources and drains) are made by boron diffusion. Substrate is then oxidized on 70 nm thick it follows a deposit by LPCVD (Low Pressure Chemical Vapor Deposition) of a layer of 100 nm thick silicon nitride which acts as sensitive layer to the H_3O^+ ions.



(a) (b)

Fig 2. (a) SEM picture showing the SU8 protection of all devices except inlet, outlet and contacts. Design of doped p-wells crossing the channel area is zoomed.(b) SEM picture after releasing sacrificial layer.

Then a 800 nm thick sacrificial layer made of S1818 photoresist is deposited by spin coating and the top of this sacrificial layer is then protected by a 100 nm thick silicon dioxide layer deposited by radio frequency sputtering. After this oxide layer is then etched to open contacts with P-doped drain and source. Next step consist on a thick aluminum (3μm) layer deposit by Joule evaporation. A last 100 μm thick layer of SU8 negative photoresist is deposited by spin coating to protect the aluminum layer and also to protect the gate from mechanical stresses thanks to its elastic properties (fig 2).

Finally, after removal of the sacrificial layer, PDMS (Polydimethylsiloxane) inlet and outlet are added on the openings (fig 3).

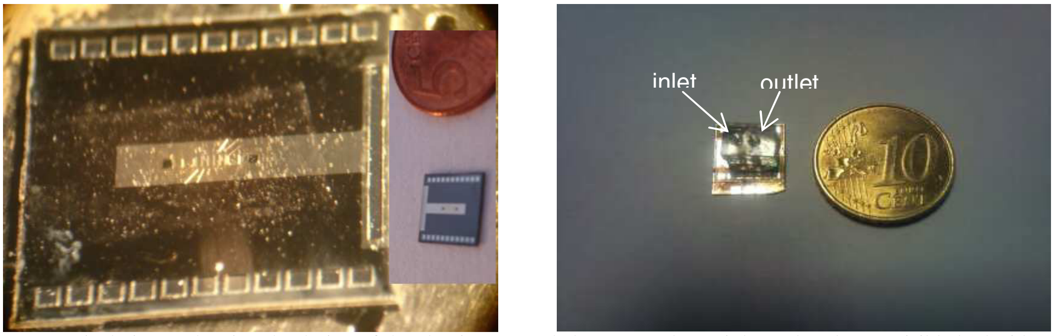


Fig 3. (a) Optical picture showing the design of the aluminum gate below a SU8 layer, inlet and outlet are visible both side of the channel. (b) Optical picture showing the block of PDMS added in the transistor.

3. Electrical test

SGFET with micro-fluidic channel have been electrically tested to show the good functioning of these devices. The following figure illustrates the output characteristic of SGFET with integrated micro-fluidic channel. The output characteristic show good modulation of drain current by the gate voltage as any classical field effect transistors.

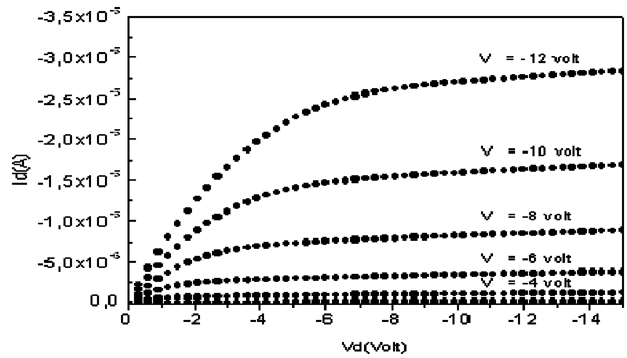


Fig 4. Output characteristics' of SGFET with integrated micro-fluidic channel without liquid injection.

The evolution of transfer characteristic of the transistor with air in the channel and water injected in the channel is clearly shown in fig 5-a. The transconductance (Gm) increases when the water is injected. This shows the good filling of water, linked to an increase of the permittivity between gate and channel, producing an increase of the transconductance. The detection of water injected is clearly shown in sampling measurement (fig 5-b). Indeed the drain current of the transistor increase when water reaches active area.

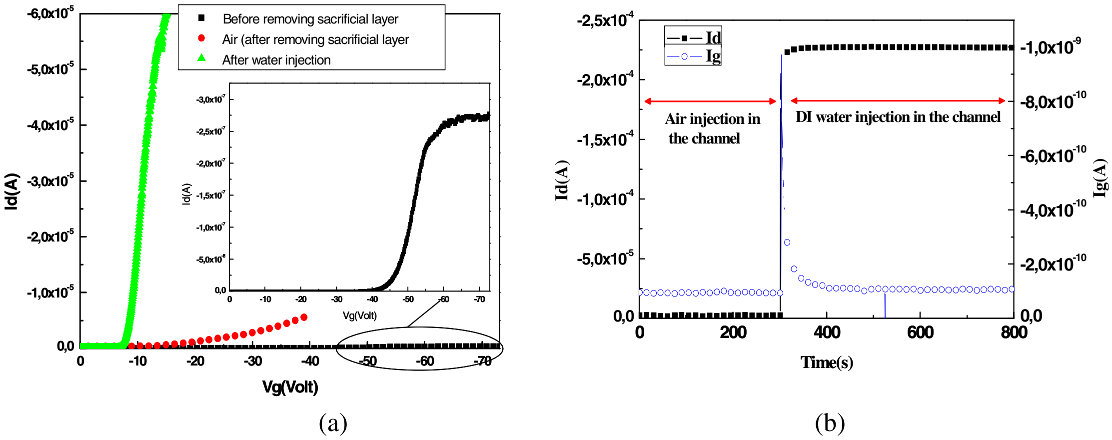


Fig 5. (a) Transfer characteristic of the SGFET at different steps of its life, before releasing, with air in the gap and finally with channel full of water. (b) Drain current (Ids) sampling showing the two operating ranges in air and DI water. Transition is direct and level of current to stable.

4. Conclusion

Micro-fluidic channels of 800nm height and 80µm width have been processed by surface micromachining. The top of this channel acts also as a gate performing by this way a SGFET with an integrated microfluidic channel. Electrical tests have shown that SGFETs are still effective after removal of the sacrificial layer and that these devices could soon increase SGFET's sensors performances especially for pH measurement.

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